CONTAMINATION OF THE FETCH-LIMITED DIRECTIONAL WAVE SPECTRUM BY WAVES EMANATING FROM AN EMBAYMENT

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Abstract

The Surface Contour Radar (SCR) has been used to map the evolution of the fetch-limited directional wave spectrum (DWS) off the eastern seaboard. Flight lines were displaced both north and south of the Delaware Bay following the passing of a weather front. The near shore DWS was found to be dominated by waves emanating from the Delaware Bay for distances of at least 85 km up the coastline and out to sea for 200 km from the mouth of the bay.

Keywords: Directional wave spectra, fetch-limited, embayment.

Introduction

The Surface Contour Radar (SCR) was developed jointly by NASA GSFC, Wallops Flight Facility (WFF) and the Naval Research Laboratory under the NASA Advanced Applications Flight Experiments (AAFE) program. It is an airborne, computer-controlled, 36 GHz bistatic radar which produces in real-time a topographical map of the surface beneath the aircraft as a false-color coded display on a TV monitor. The SCR (Fig. 1) scans a pencil-beam (0.85° x 1.2°) across the aircraft ground track twenty times a second to measure the slant range to 51 evenly spaced points. The off-nadir angle is used to convert the slant range to an elevation. Since it involves direct range measurements the SCR is one of the most straightforward remote sensing instruments.

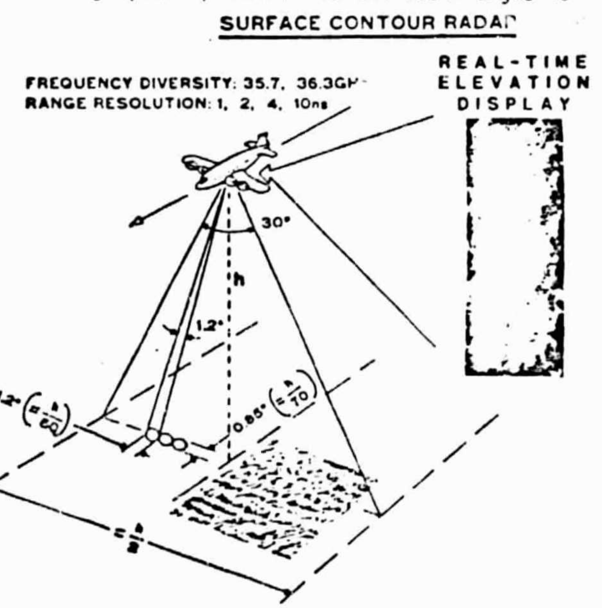

Figure 1.--Basic measurement geometry of the SCR. The display at the right is actual SCR sea surface elevation data, grey-scale coded with troughs dark and crests light.

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Post-flight programs remove the aircraft vertical motion through the use of accelerometer data and apply a two-dimensional FFT to produce directional wave spectra (DWS). The system configuration is described by Kenney et al.[1] and the data acquisition, processing, and a comparison with the XERB pitch-and-roll buoy are described by Walsh et al.[2] The SCR has been used to measure the evolution of the DWS with fetch.[3] This paper examines the major contamination of the fetch-limited spectrum by waves emanating from the Delaware Bay.

Contamination of the Fetch-Limited DWS

Flights were made on October 7, 1981, January 5, 1982, and March 27, 1982 off the eastern seaboard following cold air outbreaks. On each of the days the wind speeds and directions measured at the 400 m aircraft altitude were nearly constant in the downwind direction over the measured fetch (about 15 m/s on 10/7/81, 22 m/s on 1/5/82, and 14 m/s on 3/27/82). The starting points for the flight lines were displaced 120 km south and 25 and 85 km north of the Delaware Bay.

Since the wind directions on the three days (290° to 300°) were nearly perpendicular to the mean shoreline the conditions seemed ideal to study the evolution of the directional wave spectrum with fetch. However, analysis of the data indicates that only on the southern flight line where the near shore water was shielded by intervening land did the spectrum begin to grow in the expected manner. On both of the northern flight lines the near shore spectra were completely dominated by waves emanating from the mouth of the Delaware Bay and propagating at angles up to 45° off the wind direction.

The FFTs producing the DWS are applied to data segments of 1024 raster scan lines. The SCR produces scan lines at approximately 20/s and with a typical downwind ground speed of 120 m/s the FFTs cover distances of approximately 6 km along the ground track. The swath width for a 400 m aircraft altitude would be only 214 m. This asymmetry in the along-track and cross-track dimensions leads to an approximately 28:1 ratio in the along-track and cross-track resolutions in k-space. Figure 2 shows some of the ground tracks made on two of the days where the heavy dots indicate the centers of the segments. Some of the segment centers have radials drawn to them from the center of the mouth of the Delaware Bay for reference. On 10/7/81 the aircraft zig-zagged in the downwind direction while on 1/5/82 the aircraft proceeded directly downwind. After the downwind and upwind legs were completed on the January flight, a pass was made parallel to the New Jersey coastline down across the mouth of the Delaware Bay.

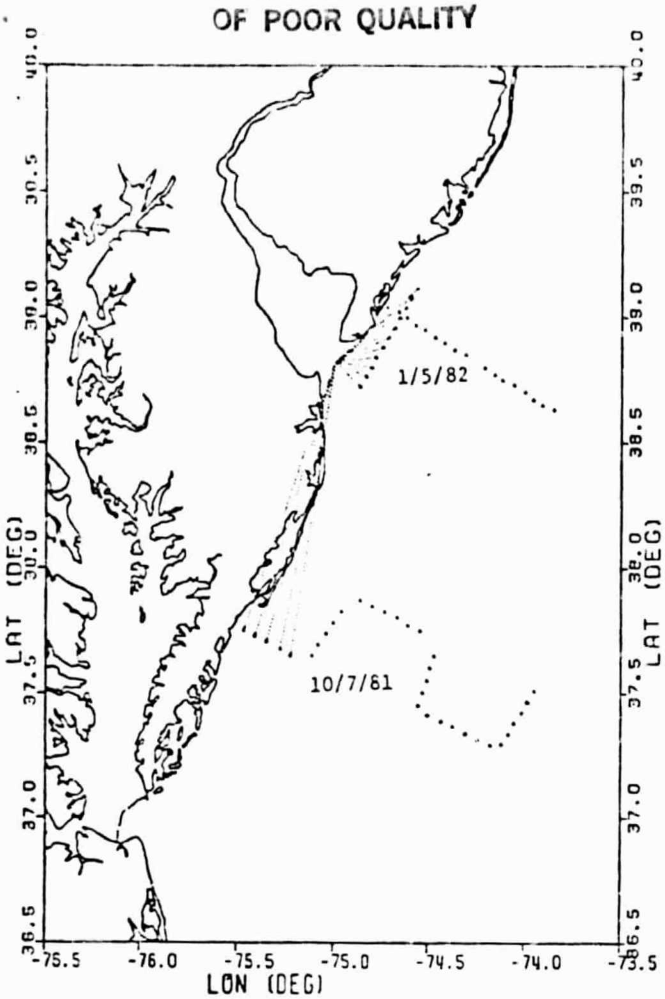

Figure 2.--Aircraft positions (heavy dots) and some radials (light dots) indicating the bearing from the mouth of the Delaware Bay.

Figure 3 shows the first six FFTS from the downwind leg on 1/5/82 with superimposed radials indicating the direction from the mouth of the Delaware Bay. The vertical scale factor on these variance spectra increases linearly with fetch so any component of constant magnitude in the sequence is actually increasing linearly. The 180° symmetry apparent in the spectra is a result of the ambiguity in the propagation direction when elevation data are transformed by an FFT. A given wave train could be propagating in either direction. However, the Doppler shifts associated with data taken on various ground tracks can be used to unambiguously eliminate the ambiguity.[2] This analysis indicates that the only onshore waves present are the swell near the center of the spectra. The spikes near the origin in the cross-track direction (most apparent in spectrum 1 which had the smallest amplitude scale factor) are due to residual aircraft motion not removed by the accelerometer. It is apparent that the dominant part of the high wave number portion of the spectra are the waves emanating from the mouth of the Delaware Bay. Even on the flight made on 3/27/82, starting from a point 85 km north of the Delaware Bay near Atlantic City, NJ, the wave field was dominated by waves from the Delaware Bay.

Figure 4 shows the DWS from the pass parallel to the New Jersey shoreline on 1/5/82. Only the higher wave number region (0.1 to 0.3 m^{-1}) is shown and arrows have been included to indicate the direction from the Delaware Bay. A number of interesting things are apparent in the sequence. In general, the spectra shift from northeast to southeast, following the radials from the Delaware Bay. However, the two northernmost spectra are actually further north than the radials. Since Fig. 2 indicates that these radials graze the shoreline, part of the wave energy probably arrived in that region due to diffraction. That could also account for the energy being highest in the first spectrum and then waning over the next three. Spectra 5 through 10 have peaks which are south of the radial from the Delaware Bay which is reasonable from Fig. 2 since the mouth of the Delaware Bay is not a point source. The radial associated with the last spectrum, which is also the most intense, is centered on the spectral peak and Fig. 2 shows that this radial is in the downwind direction and nearly aligned with the axis of the Delaware Bay.

Downwind DWS Growth

Figure 5 shows the last four spectra from the first downwind leg on 10/7/81. They clearly show the wave spectrum evolving in the downwind direction on the initial leg where the radials in Fig. 2 indicate that the intervening land sheltered the sea from the Delaware Bay. The appearance of the spectra in Figs. 3 and 5 raises the question as to whether or not the presence of waves from the Delaware Bay, propagating at angles well off the wind direction could be inhibiting the growth of the downwind wave field on 1/5/82. Figure 6 shows that the peak spectral density in the downwind direction (determined by averaging over 30° azimuthally and 0.03 m^{-1}) for the first five spectra of 1/5/82 actually grew faster as a function of fetch than it did on 10/7/81. Figure 7 shows that the wave number at the spectral peak was lower at a given fetch on 1/5/82 than it was on 10/7/81. Since the windspeed was higher for the January flight than it was in October, these differences are in the expected directions and there is no obvious inhibiting of the growth of the downwind wave field on 1/5/82 as there would have been if the differences had been reversed.

Figure 8 shows the last four spectra on the last downwind leg on 10/7/81. It is apparent that even with the spectrum initially evolving in the downwind direction, once the distance from shore was great enough so there was no intervening land, the waves from the Delaware Bay predominated. Figures 5 and 8 also indicate the presence of an overshoot in the downwind growth of the spectrum. As was mentioned earlier, the spectra are scaled with fetch so that any component whose variance is increasing linearly with distance from shore will appear the same size in all the spectra. It is obvious that the downwind wave field is growing faster than linear in Fig. 5. Figure 6 shows that this effect occurs on both 10/7/81 and 1/5/82 since the curves would have been at a 45° angle had the growth been linear with fetch. However, the spectral growth does not continue at that faster than linear rate because the peaks of the downwind portion of the wave spectra in Fig. 8 are reduced from the peak in the last spectrum of Fig. 5.

Conclusions

The fetch-limited DWS is severely contaminated by waves emanating from the Delaware Bay for at least 85 km up the coastline and 200 km out to sea. It is not obvious that the presence of the waves from the embayment have any inhibiting effect on the evolution of the downwind DWS, which exhibits an overshoot phenomenon in its growth. This data throws into doubt all earlier data on the characteristics of wave growth measured with non-directional systems such as Schule *et al.*[4] because they would not even know when they were being contaminated.

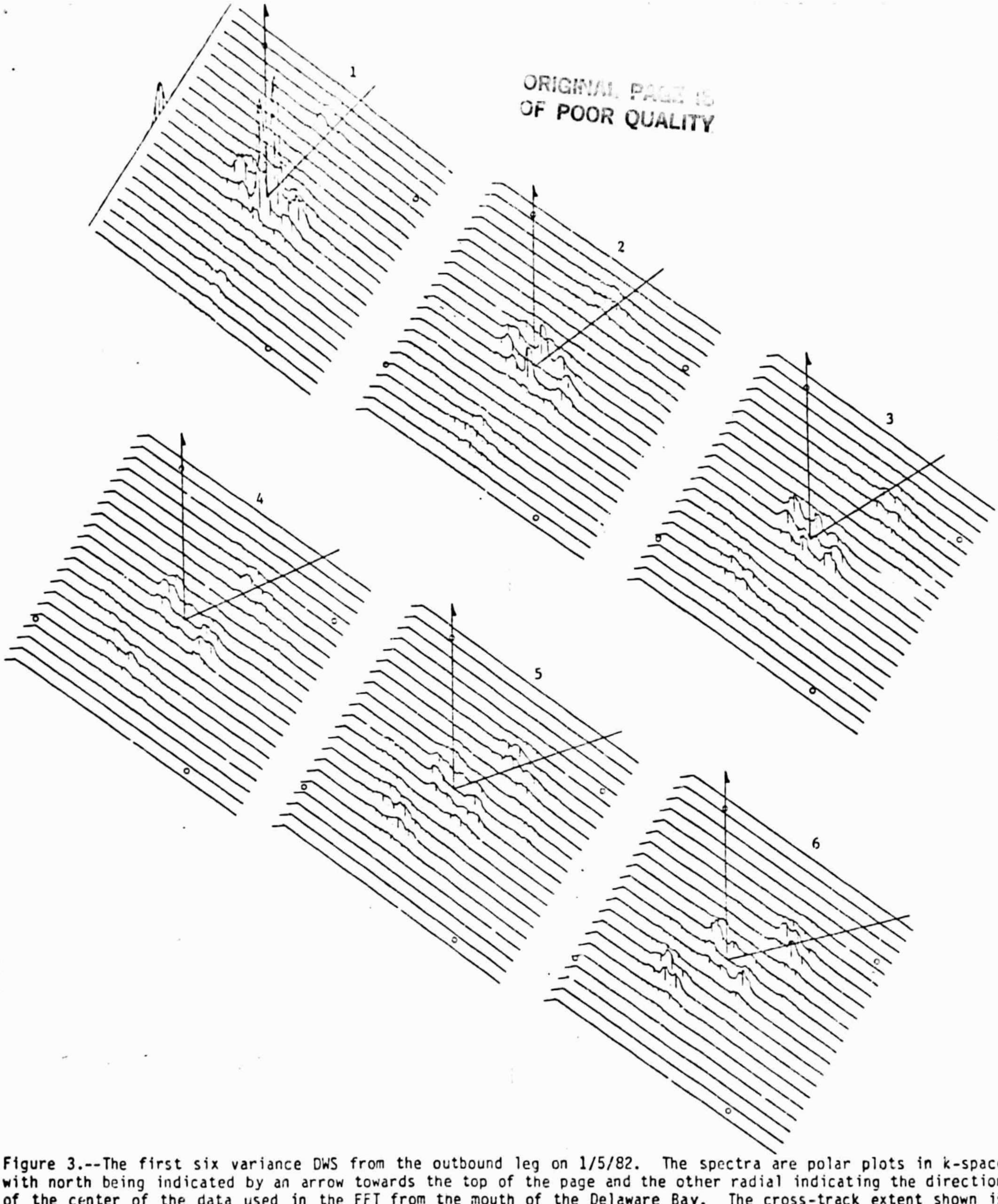

Figure 3.--The first six variance DWS from the outbound leg on 1/5/82. The spectra are polar plots in k-space with north being indicated by an arrow towards the top of the page and the other radial indicating the direction of the center of the data used in the FFT from the mouth of the Delaware Bay. The cross-track extent shown is +0.25 m^{-1}. The along-track extent in the encounter spectra was the same as the cross-track but the actual spectra shown here are slightly shifted in the along track direction. The dog-legs along the upper left hand edges of spectra 2 through 6 indicate the magnitude of the along-track shift and the cross-track rotation due to corrections for aircraft Doppler and drift angle (-2.6° to -3.5°) effects, respectively. The vertical scale factor for the variance density increases linearly with fetch so any component of constant apparent magnitude in the sequence is actually increasing linearly with distance from shore. The cross-track spacing of the spectral cuts is 0.025 m^{-1} and the along-track resolution is 0.001 m^{-1}. A 13-point moving average was carried out in the along-track direction before the DWS were plotted. No cross-track filtering was done but the $(\sin x/x)^2$ weighting function shown along the upper left hand edge of spectrum 1 indicates the actual sampling function in k-space associated with each cross-track spectral estimate of the FFT.

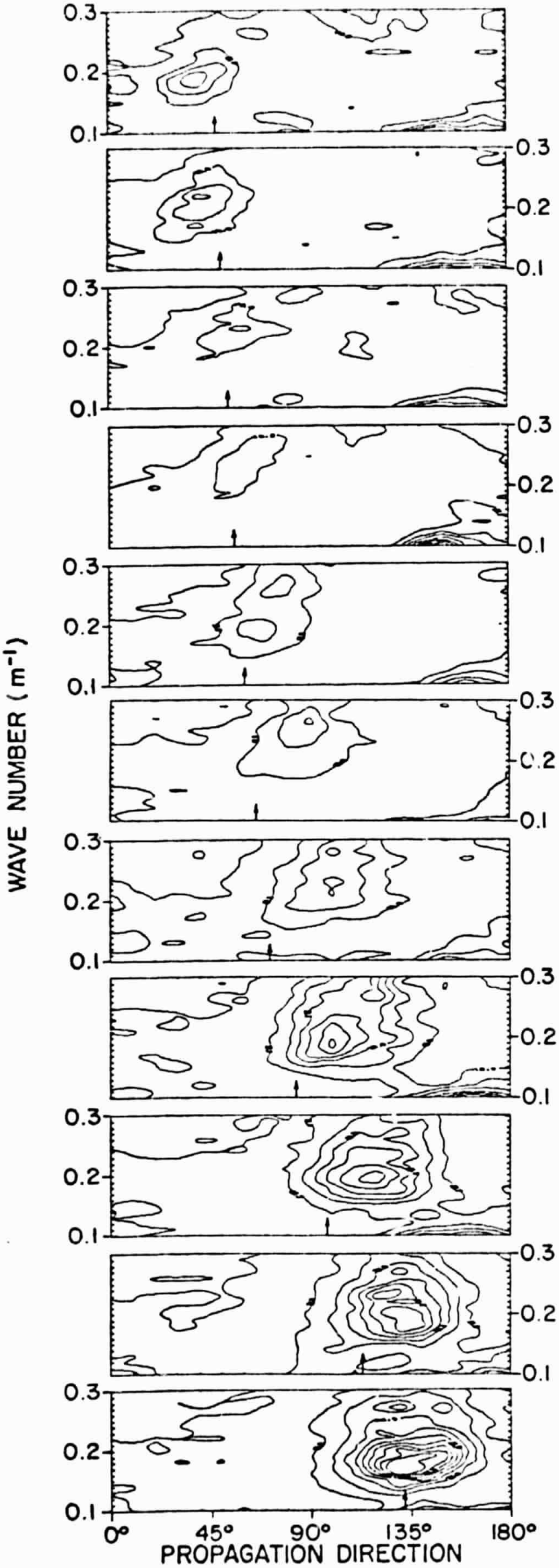

Figure 4.--The sequence of DWS associated with the eleven positions on the flight line parallel to the New Jersey coastline on 1/5/82.

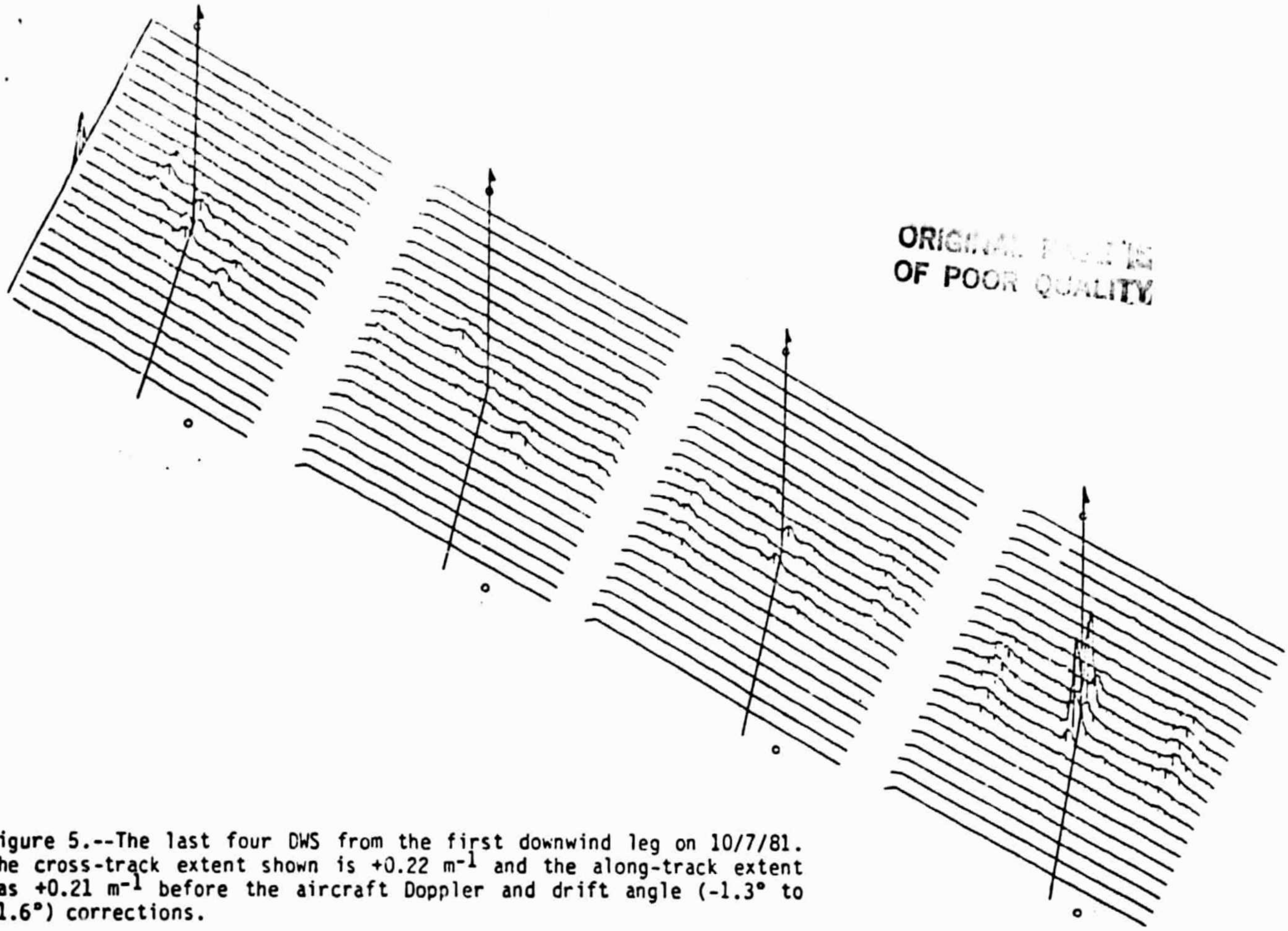

Figure 5.--The last four DWS from the first downwind leg on 10/7/81. The cross-track extent shown is +0.22 m^{-1} and the along-track extent was +0.21 m^{-1} before the aircraft Doppler and drift angle (-1.3° to -1.6°) corrections.

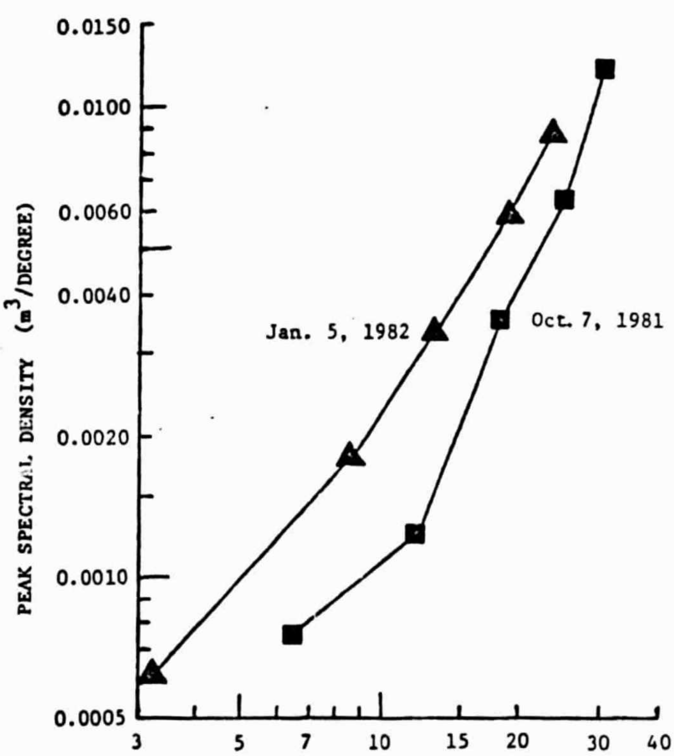

Figure 6.--Peak spectral density in the downwind direction versus fetch for the first five spectra on the downwind legs of Fig. 2.

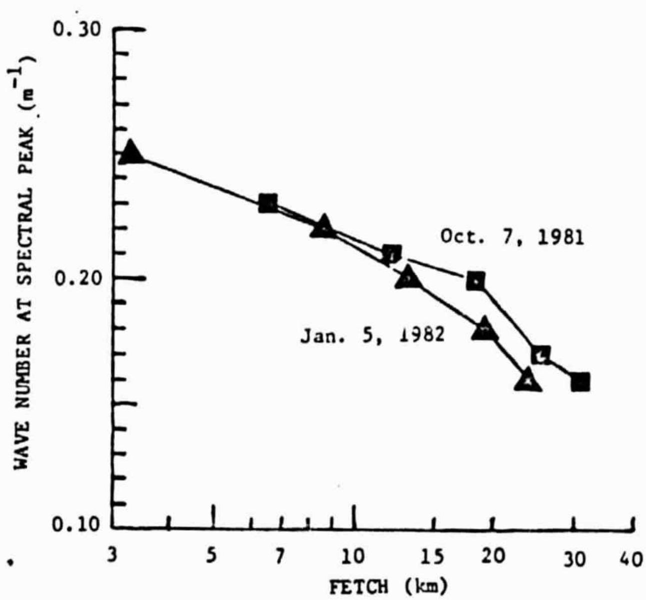

Figure 7.--Wave number at the spectra peak in the downwind direction versus fetch for the first five spectra on the downwind legs on Fig. 2.

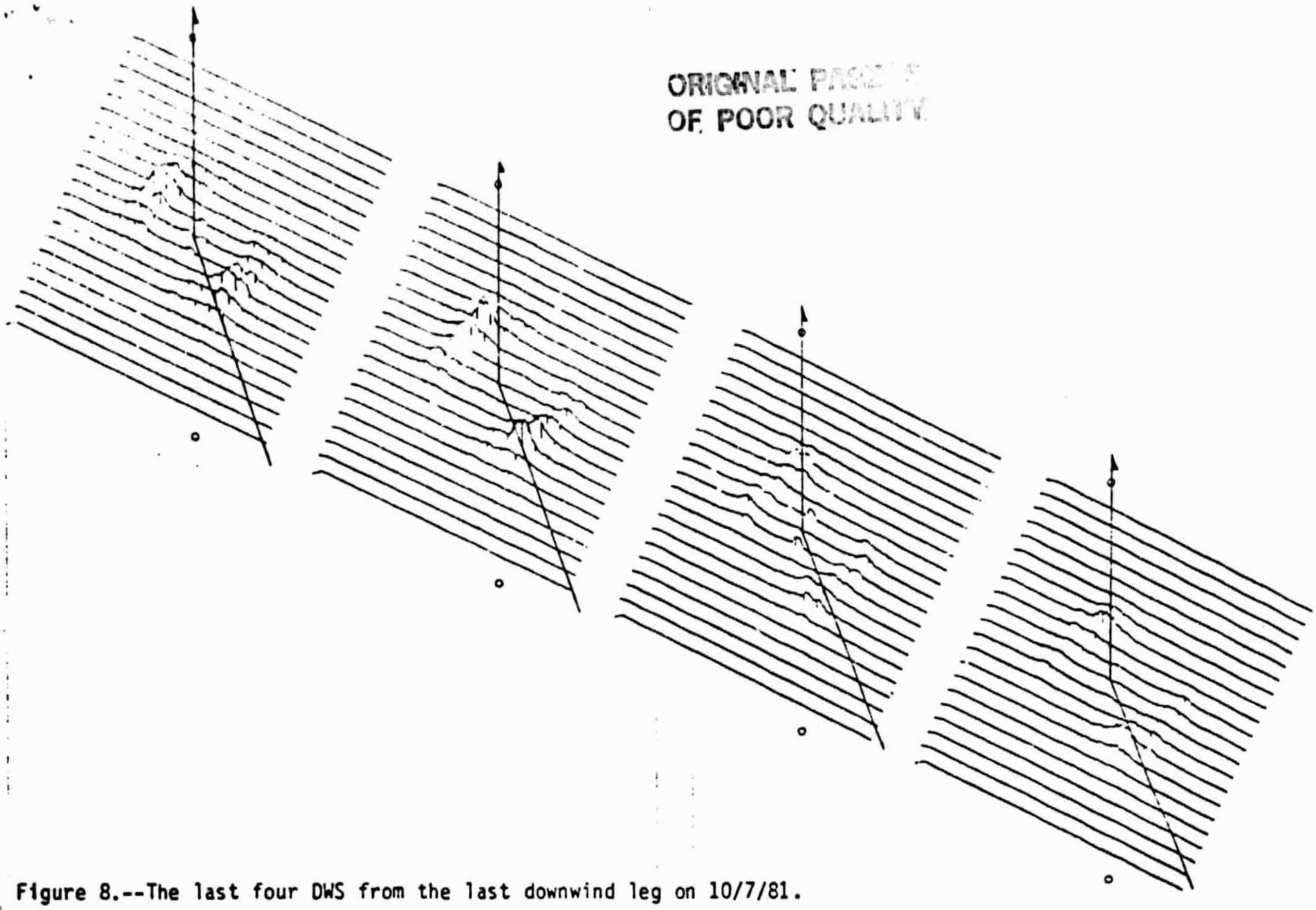

Figure 8.--The last four DWS from the last downwind leg on 10/7/81.

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